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Survey of Coastal Revetment Types

by

Bruce L. McCartney

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A review of 25 selected revetment types and a procedure for revetment design which includes identification of controlling site conditions, a comparative cost analysis method, and an example problem are presented. Design information on each type is listed in an Appendix. Design data include prototype installation examples, available model test results, and estimates of zero-damage wave heights, wave runup, and revetment wave reflection properties.

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PREFACE

This report is published to assist coastal engineers in the planning, design, and construction of coastal revetment types. The work was carried out under the coastal construction research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by Bruce L. McCartney, formerly with CERC, under the general supervision of Dr. Robert M. Sorensen, Chief, Coastal Structures Branch, Research Division.

The author appreciates the advice and comprehensive reviews by Mr. Robert Jachowski, Chief, Design Branch and Mr. John Ahrens, Coastal Structures Branch, CERC.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79*th* Congress, approved 31 July 1945, as supplemented by Public Law 172, 88*th* Congress, approved 7 November 1963.

JAMES L. TRAYERS
Colonel, Corps of Engineers
Commander and Director

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SURVEY OF COASTAL REVETMENT TYPES

by
Bruce McCartney

I. INTRODUCTION

Industrial and recreational development have caused shore-front property in many areas to become very valuable. As land values have increased, concern about the natural process of shoreline erosion has grown. This concern has resulted in the investigation of suitable coastal protection measures.

The magnitude of coastal erosion in the United States was reported in *The National Shoreline Study* (U.S. Army, Corps of Engineers, 1971) which listed 20,500 miles of eroding shoreline on the Atlantic, Pacific, gulf, and Great Lakes. These eroding shorelines include both sheltered beaches with low to moderate wave attack and exposed beaches with a high wave attack. Construction of beach protection can cost as low as $50 per lineal foot on sheltered coasts to in excess of $1,000 per lineal foot on exposed coasts. Assuming an average shore protection cost of $200 per lineal foot, protection of the 20,500 miles of eroding coast would cost over $21 billion.

Shoreline erosion can be controlled by the following methods of beach protection: (a) revetments, (b) groins, (c) breakwaters, (d) beach restoration, (e) vegetation, or (f) combinations of two or more of these. Each method has slightly different characteristics so one is usually more suited for a given site than the others. The choice of protection method will depend on the beach character, wave climate, and project purpose. The advantages and limitations of most of these methods are discussed in the *Shore Protection Manual* (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1973).

This report is concerned with revetment types of beach protection that could be constructed of materials available in most areas in the United States. Other beach protection methods will not be discussed further.

A *revetment* is defined as a facing of resistant material, such as stone or concrete, built to protect a scarp, embankment, or shore structure against erosion. The major components of a revetment are the armor face, filter, and protective toe (Fig. 1).

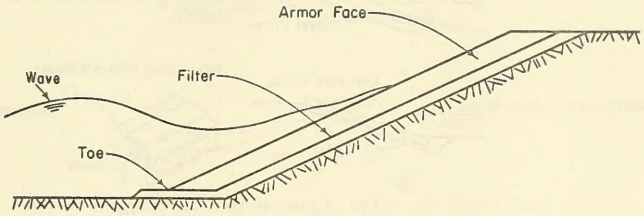


Figure 1. Revetment components.

II. REVETMENT ARMOR FACE TYPES

Revetments have been built of a variety of materials, including rock and concrete which are the most durable in water. From the numerous revetment designs, both tested and untested, 25 alternative revetment types were selected for presentation in this report. These revetments, summarized in Figure 2, could be constructed from materials available in most areas. Additional information on the merits and performance of the 25 revetments is in the Appendix.

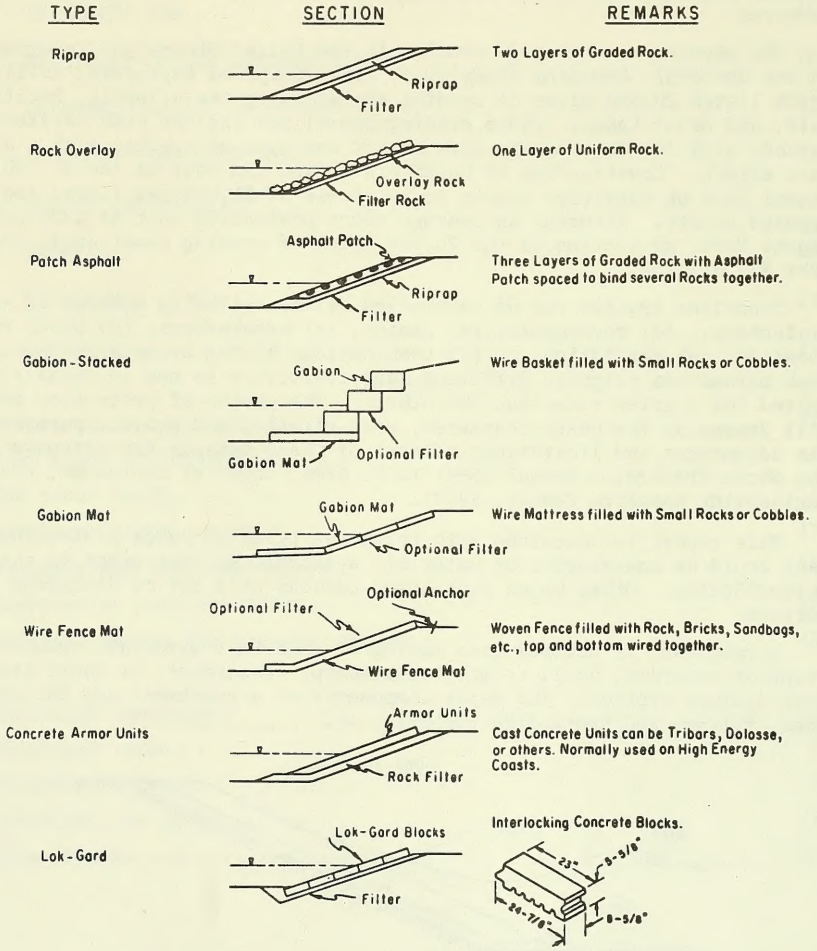


Figure 2. Revetment types.

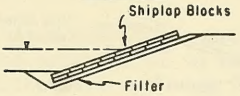
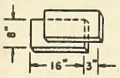
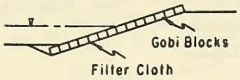
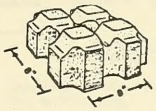
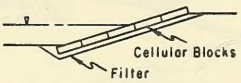
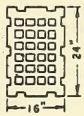
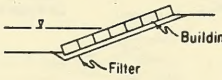
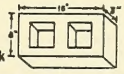
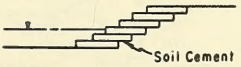
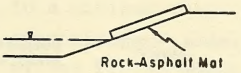
TYPE	SECTION	REMARKS
Shiplap Blocks		Concrete Blocks glued with Epoxy.  Top Perspective
Gobi Blocks		Blocks laid or glued to Filter Cloth. 
Cellular Blocks		Cellular Block Top View 
Building Blocks		 Building Block Top Perspective
Nami Rings		Rings are Concrete Pipe segments 1 ft. high, 2 1/2-ft. diameter, 3-in-thick wall, weight 265 lbs.
Soil Cement		Stairstep Soil Cement Lifts 6 in. to 1 ft. thick.
Asphalt		Compacted Asphalt 4 in. to 1 ft. thick.
Rock-Asphalt Mat		One layer of Rock covered with a thin layer of Asphalt.

Figure 2. Revetment types.--Continued

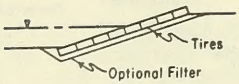
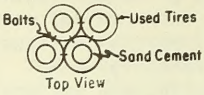
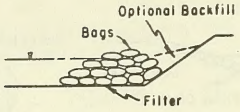
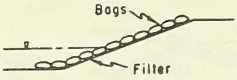
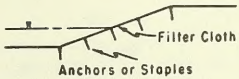
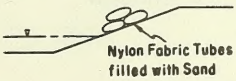
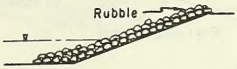
TYPE	SECTION	REMARKS
Tire Mat		Tires bolted together and filled with Sand Cement for Ballast. 
Sand-Cement Bags, stacked		Bags 60 to 100 lbs.
Sand-Cement Bags, blanket		Bags 60 lbs. and up filled in place. Gravel-filled Bags could also be used.
Nylon Mat with Ballast		Nylon Fabric Mat filled with Concrete, Sand Asphalt, or Sand. Also Pockets can be sewn on Nylon Fabric and filled with Rock Ballast.
Landing Mat		Mat made of Fiberglass, Steel, or Aluminum. May require Anchors.
Nylon Filter Cloth		Sand Anchors could also be used (see figure 3).
Sand Tubes		Tube diameter 3 ft, length up to 300 ft. Sand pumped into Tube as a Slurry.
Grass		Suitable for infrequent Waves. Wave heights less than 1 ft.
Rubble		Dumped Rubble could be Concrete, Asphalt, Bricks, Building Blocks, etc.

Figure 2. Revetment types.--Continued

III. REVETMENT FILTERS

A *filter* (Fig. 1) is a transitional layer of gravel, small stone, or fabric between the fine material of an embankment and the revetment armor. The purposes of the filter are to: (a) Prevent fine embankment material from being pulled through the armor, (b) distribute the concentrated armor unit weight to prevent settlement, and (c) to provide relief of hydrostatic pressures inside the embankment. An adequate design for most permanent revetments will require a filter. Some common filters and their application are shown in Figure 3.

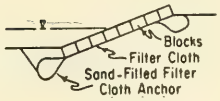
TYPE	SECTION	REMARKS
Gravel		Gravel 12 in. to 24 in. thick. Quarry Spalls 18 in. to 36 in. thick.
Quarry Spalls and Filter Cloth		Filter Cloth is open-weave Monofilament, Polyvinylide Chloride, or Polypropylene. (Barrett, 1966)
Filter Cloth		Armor Rock placed directly on Filter Cloth can tear Cloth; however, this method has occasionally been successful. (Barrett, 1966)
Filter Cloth		Cloth for Filter, Gravel for Hydrostatic Uplift Pressure Relief. (Barrett, 1966)
Filter Cloth Anchor		Anchor could be filled with Sand, Gravel, or Rocks. (Cox, 1971)

Figure 3. Revetment filters.

The general requirement for a rock or gravel filter for a riprap revetment is: D_{15} riprap/D_{85} filter ≤ 4, i.e., the diameter of the riprap 15-percent size fraction must be equal to or greater than four times the 85-percent size fraction of the filter layer (Ahrens, 1975). D_{15} identifies the grain diameter in a sample-size gradation where 15 percent of the sample is smaller. A standard riprap gradation range is from a maximum weight of $4W_{50}$ to a minimum weight of $W_{50}/8$ (U.S. Army, Corps of Engineers, 1971). The approximate W_{15} weight of $0.4W_{50}$ and W_{85} weight is $2W_{50}$. All underlayers of the riprap armor should meet the $D_{15}/D_{85} \leq 4$ criteria. Additional information on rock filters is found in the SPM, chapter 7.

IV. REVETMENT TOE

The revetment toe often requires special treatment because the toe is subjected to both hydraulic forces and the changing profiles of the beach fronting a revetment. Toe stability is an essential consideration since toe failure usually triggers failure of the upper revetment. Toe protection is generally difficult to construct since it is usually underwater and must be placed without visual guidance.

The mechanisms which cause toe scour are wave breaking, if near the toe, and the runup and runback involved in reflection of the incident wave. Incident wave runup and runback are dependent on the revetment roughness and slope, water depth, and wave steepness. Therefore, wave reflection is also dependent on these parameters. An estimate of wave reflection for each revetment type is presented in the Appendix. These estimates compare revetment porosity and roughness for revetments of the same slope. The present knowledge of the causes and effects of toe scour is too limited to estimate reflection coefficients for both revetment slope and roughness. Generally, the flatter the revetment, the lower the wave reflection, and the smaller the toe scour due to runup and runback. Also, the rougher and more permeable the revetment surface, the lower the wave reflection, and smaller the toe scour. A flat slope, rough, permeable revetment should have the least toe scour.

Another factor that affects toe scour-hole size is the beach sand size that fronts the revetment. Fine-grain sand beaches are more erodable than coarse-grain beaches.

Toe-scour problems can be avoided by adequate toe protection in the revetment design. Some common types of toe protection are shown in Figure 4.

V. REVETMENT DESIGN CONSIDERATIONS

If a revetement is selected as the most suitable means of protecting an eroding shore front, the next step is to determine the best revetment type. This requires an analysis of how alternative revetments will interact with site conditions and the resulting cost of these revetments. Considerations for an adequate revetment design are:

(a) Design Life of Project. Design life is short for temporary structures like embankment protection for a coffer dam, but long for nuclear powerplant embankment revetments.

(b) Design Wave. Select a wave height and wave period consistent with the project design life. The wave characteristics are based on analysis of wave gage, observed wave data, or wave hindcasts as described in the SPM, chapter 3. This report assumes the zero-damage wave height (see App.) is measured at the revetment toe. The design wave is needed to determine the size of the revetment armor units, estimate wave runup, and predict potential toe scour.

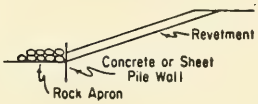
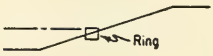
TYPE	SECTION	REMARKS
Apron		Apron will slough into Scour Hole if one develops; Revetment integrity will remain.
Buried Toe		
Weighted Toe		
Weighted Toe		Filter Cloth encloses Gravel Bulb at Toe. (Barrett, 1966)
Weighted Toe		(Mohl, 1967)
Flexible Mat		Mat could be Gabion or Filter Cloth filled with Sand.
Offshore Sill		Sill Traps Sand which buries Revetment Toe. (Sivard, 1971)
Beach Feed		Stockpile feeds Toe to replace Toe Scour Losses.
Cutoff Wall		(SPM)
Antierosion Rings		Rings are Concrete Pipe Segments, 2 ft. to 4 ft. high with 4 ft. to 5 ft. Diameters. A row of Shore-parallel Rings builds a perched Beach. (Portland Cement Association, 1955)

Figure 4. Revetment toe protection.

(c) Seasonal Variations on Beach Profile. Beach recession in winter and growth in summer can be estimated by site inspection and seasonal beach profile variation. The extent of winter beach profile lowering will be a contributing factor in determining the type and extent of toe protection needed.

(d) Water Level Range. Changes in water level on the revetment can be caused by tides, storm surge, or seasonal water level changes due to runoff (lake levels). Predicted tidal ranges are published by the National Oceanic and Atmospheric Administration; storm surges can be estimated by methods described in the SPM, chapter 3; seasonal level data may be available through State or local government agencies. Maximum water levels establish the stillwater level for estimating wave runup. Toe-scour estimates should be based on the minimum water level.

(e) Beach Composition. The foreshore, berm, and backshore beach material-size gradations are necessary to determine the revetment filter requirements.

(f) Beach Use. Beach use for recreation and other purposes may dictate use of upper beach revetment to contain runup and sandfill on the beach face seaward of the revetment.

VI. REVETMENT DESIGN PROCEDURE

The previously listed design considerations must be satisfied to ensure an adequate revetment design. Generally the most desirable revetment would have to be stable under the design wave attack, have a rough and permeable surface to reduce wave runup and reflection, and be flexible for satisfactory adjustment to settlement and scour. Detailed design procedures as described in the SPM are summarized as follows:

(a) Armor Unit Size. Determine armor unit size for stability under design wave for specified slope (App.; SPM, ch. 7).

(b) Runup Elevation. Determine runup elevation of design wave height and period for specific revetment slope and roughness (App.; SPM, ch. 7).

(c) Toe-Scour Depth. Determine toe-scour depth for design wave for specific revetment slope and revetment wave reflection (App.; SPM, ch. 5).

(d) Toe Protection Type. Determine toe protection type based on amount of allowable scour (Fig. 4).

(e) Revetment Slope Length. Determine revetment slope length, based on runup, water level changes, and toe scour (SPM, ch. 7).

(f) Filter Type. Determine filter type, based on embankment gradation and revetment armor characteristics (Fig. 3).

VII. ECONOMIC CONSIDERATIONS

An economic analysis of revetment plans can be made by comparing initial construction and design-life maintenance costs for the revetments considered to select the final design. Some design considerations are organized into a matrix which can be used to compare alternative revetment designs (Table 1).

Table 1. Revetment analysis matrix.

Revetment type	Design life (years)	Design wave	Allowable damage	Water level range (feet)	Revetment slope	Roughness coefficient	Wave runup	Reflection coefficient	Toe scour	Revetment slope length	Armor unit weight (pounds)	Filter type	Toe type	Initial cost	Maintenance cost	Annual cost

The size of the matrix will depend on the number of independent variables allowed to change in an analysis. These independent variables are:

(a) Revetment type,
(b) design life,
(c) allowable damage,
(d) revetment slope,
(e) filter type (semi-independent), and
(f) toe type (semi-independent).

VIII. USE OF THE MATRIX

The following is an example of how to use the matrix (Table 1):

********** EXAMPLE PROBLEM **********

GIVEN:

(a) 100 feet of low bluff on Lake Superior is eroding. Bluff slope is about 1 on 3.

(b) Design life, 20 years (selected).

(c) Design wave H = 5 feet at toe of structure; period T = 7 seconds.

(d) Zero-percent damage criteria.

(e) No overtopping allowed.

(f) Lake level range 3.8 feet.

(g) Storm surge 2.2 feet.

(h) Water depth at toe of revetment is 4 feet below minimum lake level.

(i) Beach slope M = 1:20.

FIND:

Revetment type with lowest annual cost (Fig. 5). Consider the following: (a) Riprap, (b) Gabion mat, (c) Lok-Gard concrete blocks, and (d) car tire mat filled with sand cement.

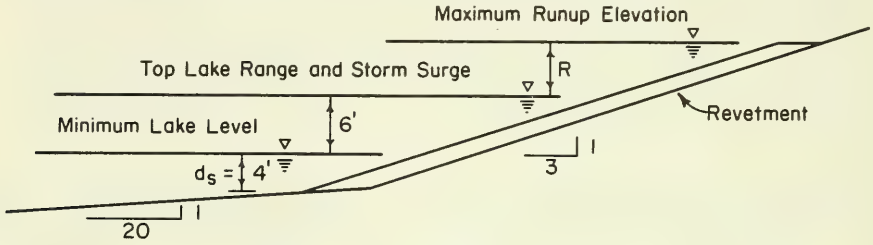


Figure 5. Site sketch (section).

DEFINITIONS:

T = wave period (seconds).

H = design wave height at structure toe (feet).

H'_o = deepwater wave height (unrefracted) (feet).

d_b = water depth when wave breaks (feet).

d_s = water depth at toe of structure (feet).

R = wave runup height above stillwater level (SWL) (feet).

PROCEDURES:

Step 1. Water Level Range: The water level range at the revetment is the sum of:

lake level range	= 3.8 feet
storm surge	= 2.2 feet
	6.0 feet

Step 2. Slope: Use a 1 on 3 revetment slope to be compatible with the bluff slope.

Step 3. Roughness Coefficient: Roughness coefficient is the ratio of rough slope runup to smooth slope runup. This coefficient is listed in the Appendix as the factor which reduces smooth slope runup.

Step 4. Wave Runup on Revetment (Table 2):

Find wave runup for a smooth 1 on 3 slope.

Depth of water at maximum SWL is 6 feet + 4 = 10 feet.

Find wave breaking depth.

Assume:

$$H = H_b = 5 \text{ feet},$$

$$\frac{H_b}{T^2} = \frac{5}{7^2} = 0.102.$$

From the SPM, Figure 7-2:

$$\frac{d_b}{H_b} = 0.95,$$

$$d_b = 5 \times 0.95 = 4.75 \text{ feet}.$$

Since water level at structure is between 4 and 10 feet, wave will break on structure.

From runup for maximum water depth (10 feet).

From the SPM, Figure 7-5:

$$\frac{H_b}{H'_o} = 1.56,$$

$$H'_o = \frac{5}{1.56} = 3.2 \text{ feet};$$

therefore,

$$\frac{d_s}{H'_o} = \frac{10}{3.2} = 3.1,$$

and

$$\frac{H'_o}{T^2} = \frac{3.2}{7^2} = 0.065.$$

Interpolation from the SPM, Figure 7-12 is:

$$\frac{R}{H'_o} = 2.4.$$

Scale correction from the SPM, Figure 7-13 is 1.14.

Table 2. Wave runup on revetment.

Revetment Type	R'/H'_o	R	Smooth R'/H'_o	Roughness coefficient[1]	Scale correction
Riprap	1.37	4.4	2.4	0.5	1.14
Gabion mats	1.50	4.8	2.4	0.55	1.14
Lok-Gard blocks	2.60	8.3	2.4	0.95	1.14
Tire mats	1.78	5.7	2.4	0.65	1.14

1. Appendix.

Step 5. Toe-Scour Depth: The maximum toe-scour depth below the natural bed is about equal to the height of the maximum unbroken wave that can be supported by the original depth of water (SPM, ch. 5).

The minimum water depth at the revetment toe is 4 feet; maximum water depth is 10 feet. The design wave at the toe of the structure is 5 feet which is a breaking wave in 4.75 feet of water.

Therefore, since a breaking wave at the structure toe is possible, the maximum estimated depth of scour would be 5 feet below the natural bed. This estimate does not consider structure shape or wave reflection properties and is probably quite conservative.

Assuming scour is less for sloping revetments with low reflection coefficients, the following estimates of scour depth are developed (Table 3).

Table 3. Toe scour depth.

Revetment Type	Scour depth		Reflection coefficient[1]
	Maximum possible (feet)	Estimated (feet)	
Riprap	5	2	low
Gabion mats	5	2	low
Lok-Gard blocks	5	4	high
Tire mats	5	3	moderate

1. Appendix.

Step 6. Slope Length: Revetment slope length is the sum of the vertical elements converted to slope distance (Table 4):

Table 4. Revetment slope length.

Revetment Type	Length (feet)	Runup R (feet)	Water level Range (feet)	Water depth (feet)	Scour depth (feet)	Vertical height Total (feet)
Riprap	51.9	4.4	6	4	2	16.4
Gabion mats	53.1	4.8	6	4	2	16.8
Lok-Gard blocks	70.5	8.3	6	4	4	22.3
Tire mats	59.1	5.7	6	4	3	18.7

Step 7. Armor Unit Weight:

Riprap Revetment. Using Hudson's (1974) equation with K_{RR} = 2.2 to calculate stable rock weight (SPM, ch. 7), the median riprap size is 700 pounds.

Gabion Mat. Dimension 12 by 3 by 1 foot, nominal volume, 1.33 cubic yards filled with rock at 1.6 tons per cubic yard. Unit weight 1.33 cubic yards by 1.6 tons per cubic yard = 2.1 tons; each mat covers 36 square feet. Estimated stable for H of 3 to 5 feet (App.).

Lok-Gard Blocks. Interlocking block 23 by 8.6 by 5.6 inches; weight 75 pounds each. Stable for 5-foot wave height (App.).

Tires. Used car tires (26-inch outside diameter) bolted through the tread and filled with sand cement. Weight about 300 pounds each. Estimated stable for H of 3 to 5 feet (App.).

Step 8. Construction Cost:

Develop quantity and cost estimates for all revetments (Table 5).

Assume the following costs:

Gabion mat (galvanized)---$24.
Riprap---$8 per ton.
Gravel---$3.50 per ton.
Cobbles (4- to 6-inch diameter)---$3.30 per ton.
Filter cloth---$0.15 per square foot.
Used tires---free.
Cement---$0.03 per pound.
Beach Sand (for sand cement)---free.
Lok-Gard blocks---$1.25 each.
Installation (estimated labor and equipment)---
$1 per square foot of revetment surface.

Table 5. Quantity and cost estimates.

Description	Unit	Quantity	Unit cost	Total cost
Riprap (Coverage 100 feet X 52 feet = 5,200 square feet)				
Riprap armor W_{50} = 700 pounds (3.25 feet thick)	tons	1,000	$ 8.00	$ 8.000
Rock underlayer W_{50} = 70 pounds (1.5 feet thick)	tons	460	$ 8.00	3,680
Gravel filter (1 foot thick)	tons	310	$ 3.50	1,085
Installation	square feet	5,200	$ 1.00	5,200
Subtotal				$17,965
Total cost including 25-percent contingency				$22,500
Gabion (Coverage 100 feet X 54 feet = 5,400 square feet)				
Gabion mat 12 feet X 3 feet X 1 foot (36 square feet each)	each	150	$24.00	$ 3,600
Cobble fill (2.1 tons each Gabion)	tons	315	$ 3.30	1,040
Filter cloth	square feet	5,400	$ 0.15	810
Installation	square feet	5,400	$ 1.00	5,400
Subtotal				$10,850
Total cost including 25-percent contingency				$13,600
Lok-Gard blocks (Coverage 100 feet X 71 feet = 7,100 square feet)				
Lok-Gard blocks (1.38 square feet each)	each	5,154	$ 1.25	$ 6,440
Gravel bedding (1 foot thick)	tons	420	$ 3.50	1,470
Filter cloth	square feet	7,100	$ 0.15	1,060
Installation	square feet	7,100	$ 1.00	7,100
Subtotal				$16,070
Total cost including 25-percent contingency				$20,100
Tires (Coverage 100 feet X 60 feet = 6,000 square feet)				
Tires	each	1,480	free	----------
Bolts with washers	each	4,440	$ 0.50	$ 2,200
Cement	pounds	29,600	$ 0.03	890
Filter cloth	square feet	6,000	$ 0.15	900
Installation	square feet	6,000	$ 1.00	6,000
Subtotal				$ 9,990
Total cost including 25-percent contingency				$12,500

Step 9. Maintenance Cost: Assume all revetments annual maintenance cost at 1 percent of initial cost (Table 6).

Table 6. Comparative cost estimates.

Revetment	Capital recovery		Maintenance	Cost	
Type	Factor	Annual	Annual	Construction	Annual
Riprap	0.08718	$1,962	$ 230	$22,500	$2,192
Gabion mats	0.08718	1,186	140	13,600	1,326
Lok-Gard blocks	0.08718	1,752	200	20,100	1,952
Tire mats	0.08718	$1,090	$ 130	$12,500	$1,220

Step 10. Annual Cost (for 100 lineal feet): Cost given in Table 6.

Assume 6 percent interest n = 20 (20-year design life).

Capital recovery factor = 0.08718.

With all the necessary information for the revetment analysis computed, the completed matrix shows that the car tire mat has the lowest annual cost and therefore, would be recommended (Table 7).

Table 7. Analysis matrix for example problem.

Revetment type	Design life (years)	Design wave	Allowable damage	Water level range (feet)	Revetment slope	Roughness coefficient	Wave runup	Reflection coefficient	Toe scour	Revetment slope length	Armor unit weight (pounds)	Filter type	Toe type	Unit cost	Maintenance cost	Annual cost
Riprap	20	H = 5 T = 7 s	0	6	1 on 3	0.5	4.4	Low	2	52	700	Gravel	Buried	$22,500	$230	$2,192
Gabion mat	20	H = 5 T = 7 s	0	6	1 on 3	0.55	4.8	Low	2	54	2,200	Woven plastic cloth	Apron	$13,600	$140	$1,326
Lok-Gard blocks	20	H = 5 T = 7 s	0	6	1 on 3	0.95	8.3	High	4	71	75	Woven plastic cloth	Buried	$20,100	$200	$1,952
Tire mat	20	H = 5 T = 7 s	0	6	1 on 3	0.65	5.7	Mod.	3	60	300	None	Apron	$12,500	$130	$1,220

To reduce the length and enhance the clarity of the example problem, the revetment type was selected as the only independent variable. However, in an actual design problem all independent variables could be considered to evaluate their effect on the annual cost. Consideration of all independent variables could make a matrix of 50 or 100 elements which would be warranted if the initial revetment cost was substantial.

IX. SUMMARY

The revetment types presented cover a wide range of traditional designs and new, untested designs. If an untested design is selected for a particular project of significant size, model studies or a prototype test section should be undertaken to provide sufficient data to design the structure.

The optimum revetment should be rough and permeable to reduce wave runup and reflection, and flexible to prevent failure during settlement. However, revetments that do not meet these requirement are still adequate when properly designed for a specific site.

Success of any revetment will depend on an accurate evaluation of wave conditions, and the prediction of beach changes after construction. It is recommended that a site-adapted design be made by a qualified coastal engineer.

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APPENDIX

REVETMENT DESIGN DETAILS

RIPRAP

SECTION

Rock revetment at Chesapeake Bay, Md.

Prototype Installation:

Riprap is the most common revetment type in the United States with many prototype installations.

Wave Tank Tests:

Small scale (Hudson and Jackson, 1962).

Near prototype scale (Thomsen, Wohlt, and Harrison, 1972; Ahrens, 1975).

Design Factors:

Zero-damage wave height: Depends on rock size.

Wave runup: 0.5 compared to smooth slope.

Wave reflection: Low.

Remarks:

Design information listed in the SPM.

Riprap stability changes with slope and wave period (Ahrens and McCartney, 1975).

Economy can often be obtained by matching the riprap gradation to the local quarry-yield gradation.

Quality control in construction is needed to assure proper gradation on slope (no sections with a predominance of fines).

Minimum of two layers of riprap armor recommended with adequate filter layer.

ROCK OVERLAY

SECTION

Rock overlay in large wave tank at the Coastal Engineering Research Center (CERC).

Prototype Installation:

Lake Oahe, South Dakota.

Railroad embankment in Lake Oahe near Mobridge.

Existing riprap bank damaged by 5-foot-high waves.

Rock overlay (all rocks touching) was used to upgrade the slope stability.

Overlay design wave H_s = 5 feet.

Overlay stable after 3 years (McCartney and Ahrens, in preparation, 1976).

Wave Tank Tests:

Overlay tested in both large and small wave tanks (McCartney and Ahrens, in preparation, 1976).

Tests only for 1 on 3 slope and 3.67-period waves.

Overlay has stability equal to two layers of riprap for zero damage; however, overlay had only one-half the reserve stability as two layers of riprap.

Design Factors:

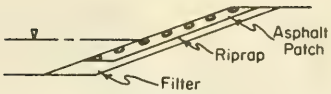
Zero-damage wave height: Depends on rock size.

Wave runup: 0.5 compared to smooth slope.

Wave reflection: Low.

Remarks:

Overlay could be used to upgrade a damaged riprap slope or as original construction.



SECTION

Prototype Installation:

Unknown locations.

Wave Tank Tests:

Model tests conducted at Delft Hydraulics Laboratory, Delft, The Netherlands.

Patches of asphalt were poured on rock slope (above and below water) to bind 5 to 10 rocks together.

Stability coefficient K_{Δ} increased two to three times over nonpatch asphalt slope (d'Angremond, et al., 1970).

Design Factors:

Zero-damage wave height: Depends on rock size.

Wave runup: 0.6 to 0.7 compared to smooth slope (estimated).

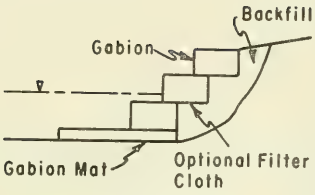
Wave reflection: Medium (estimated).

Remarks:

Patch asphalt could be used to upgrade a damaged riprap slope or as original construction.

Three layers of riprap is recommended with asphalt patch affecting only the top two layers.

The bottom layer provides protection to the core if a patch is washed out.



SECTION

Gabion-stacked revetment, Lake Erie, Sheffield Lake, Ohio.

Prototype Installation:

England.

Stacked Gabions on Gabion mat protect eroding bluff (Dock and Harbour Authority, 1965).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: 6 to 8 feet (estimated for 3- by 3- by 6-foot-long Gabion).

Wave runup: 0.5 to 0.6 compared to smooth slope (estimated).

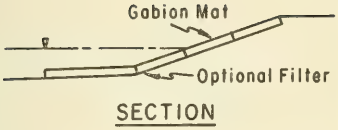
Wave reflection: Low (estimated).

Remarks:

Gabions stacked to form stairstep face.

A Gabion mat is usually suggested for toe protection.

Gabions are available with galvanized wire for freshwater and polyvinyl chloride-coated wire for saltwater.



SECTION

Gabion mat revetment on lake.

Prototype Installation:
Unknown locations.

Wave Tank Tests:
Unknown.

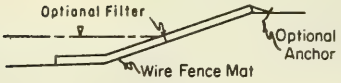
Design Factors:
Zero-damage wave height: 3 to 5 feet
(estimated for 10- to 12-inch-thick mats).

Wave runup: 0.5 to 0.6 compared to smooth slope (estimated).

Wave reflection: Low (estimated).

Remarks:
None.

WIRE FENCE MAT



SECTION

Prototype Installation:
Unknown locations.

Wave Tank Tests:
Unknown.

Design Factors:
Zero-damage wave height: 2 to 3 feet (estimated).

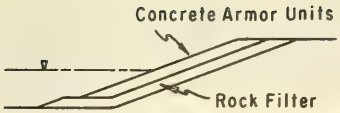
Wave runup: 0.5 to 0.7 compared to smooth slope, depending on fill material (estimated).

Wave reflection: Medium (estimated).

Remarks:
Wire fence mat is similar to the Gabion mat but not as strong.

Mat would have a wire fence top and bottom, and would be filled with rock, bricks, or rubble.

The top and bottom fencing would then be wired together.



SECTION

Tribar revetment tested at CERC.

Prototype Installation:

Concrete armor units such as tribars, tetrapods, quadripods, and dolosse have been used on many rubble-mound coastal structures. Examples are given by Hudson, 1974.

Wave Tank Tests:

Wave tank tests of several concrete armor shapes have been conducted at the U.S. Army Engineer Waterways Experiment Station (WES), CERC, and other laboratories. Some of these test results are referenced by Hudson, 1974.

Design Factors:

Zero-damage wave height: Depends on weight of unit and interlocking characteristics.

Wave runup: 0.5 to 0.8 compared to smooth slope.

Wave reflection: Low.

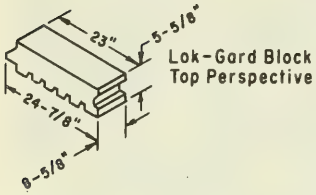
Remarks:

Different types of concrete armor units exhibit stability against wave attack two to six times greater than equal weight rock armor.

Concrete armor units are usually not cost effective where suitable-size rock is locally available.

These armor units can be used to revet the surface of a rock breakwater or an embankment.

SECTION



Lok-Gard revetment, Cedarhurst, Md.

Prototype Installation:

Tilgham Island, Maryland.

800 feet of shoreline protected by 1 on 2 slope Lok-Gard revetment.

Estimated storm wave height 5 feet (Mohl and Brown, 1967).

Wave Tank Tests:

Prototype-scale tests: Blocks stable for a 4.8-foot-high, 4.7-second wave period attack; embankment slope was 1 on 2.

The revetment was bedded on a 6-inch layer of crushed stone and plastic filter cloth (Hall, 1966).

Design Factors:

Zero-damage wave height: 5 feet (determined in wave tank tests).

Wave runup: 0.9 to 1 compared to smooth slopes (estimated).

Wave reflection: High (estimated).

Remarks:

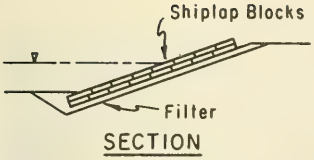
Lok-Gard units weigh 75 pounds each.

Design requires filter and toe protection.

Toe protection could be buried toe or weighted with larger rocks or concrete bags.

Revetment has little reserve stability.

SHIPLAP BLOCKS



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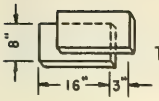


Shiplap Block
Top Perspective

Patuxent River, Calvert County, Md.

Prototype Installation:

Friendship House, Patuxent River, Maryland.
Estimated design wave height 3 feet.

Concrete patio blocks (8 by 16 by 2 inches) were fastened together in shiplap pattern with epoxy; blocks were placed on woven filter cloth.

Toe was buried.

Cost about 50 percent less than riprap (Hall and Jachowski, 1964).

Jupiter Island, Florida.
Three-foot-square Shiplap blocks alternating 10 and 14 inches thick (Wilder and Koller, 1971).

Wave Tank Tests:

Patio blocks (18 by 18 by 3 inches each) were fastened together with epoxy and tested at prototype scale in the CERC large wave tank.

This 1 on 2 slope revetment was stable for a 4-foot-high, 6-second-period wave (Hall, 1966).

Design Factors:

Zero-damage wave height: Depends on unit size.

Wave runup: 0.9 to 1 compared to smooth slopes (estimated).

Wave reflection: High (estimated).

Remarks:

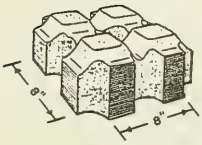
8- by 16- by 2-inch units weigh 75 pounds.

18- by 18- by 3-inch units weigh 150 pounds.

36- by 36- by 10-inch units weigh 1,400 pounds.

36- by 36- by 14-inch units weigh 1,600 pounds.

SECTION



Holly Beach, La.

Prototype Installation:

Holly Beach, Louisiana.

Revetment 3 miles long, 1 on 3 slope, with buried toe.

Forecast design waves 3.3 feet.

Revetment was subjected to five storms in first year and sustained minor damage (DeMent, 1969; Cox, 1971).

Wave Tank Tests:

1 on 3.5 slope Gobi block revetment was tested at prototype scale in CERC large wave tank.

Revetment used straight-sided blocks placed directly on filter cloth.

Zero-damage wave height about 2 feet. (McCartney and Ahrens, 1975).

Design Factors:

Zero-damage wave height: 3 feet (estimate based on Holly Beach revetment).

Wave runup: 0.8 to 1 compared to smooth slopes (wave tank tests).

Wave reflection: Moderate (estimated).

Remarks:

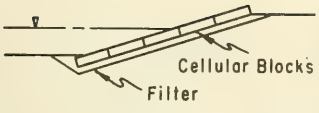
Gobi blocks came with straight or beveled sides.

Straight-sided blocks weigh 14 pounds and are placed directly on filter cloth.

Bevel-sided blocks weigh 12 pounds and can be glued to filter cloth in factory and placed as a mat.

Grass can grow through block openings which will further increase stability to wave attack.

Backfilling blocks with sand or gravel also increase revetment stability.



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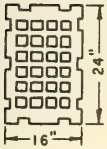


Cellular Block
Top View

Precast cellular revetment blocks being placed by hand, Buffalo Creek, N.Y.

Prototype Installation:

Buffalo Creek, New York.
1 on 2 slope revetment used on a river bend to stabilize bank (Parsons and Apmann, 1965).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: 4 to 5 feet (estimated).

Wave runup: 0.7 to 0.9 compared to smooth slope (estimated).

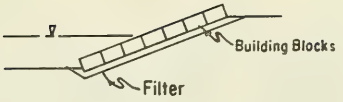
Wave reflection: Moderate (estimated).

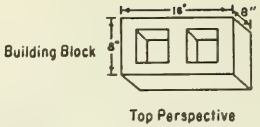
Remarks:

Cellular blocks weigh 83 pounds each.

Block size is 24 by 16 by 4 inches high with 24 2-inch-square cells per block.

Cells reduce block weight, trap littoral drift, provide uplift pressure relief, and reduce runup.





Prototype Installation:

Unknown locations.

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: 3 to 5 feet (estimated).

Wave runup: 0.7 to 0.9 compared to smooth slopes (estimated).

Wave reflection: Moderate (estimated).

Remarks:

Standard concrete building blocks are 16 by 8 by 8 inches high and weigh about 40 pounds.

Blocks should have open side up to trap littoral drift, reduce uplift pressure, and reduce runup. Backfilling with sand or gravel would increase stability.

Blocks should have a bruied toe or weighted toe with large rocks or concrete bags.

SECTION

Nami ring revetment, Little Girl Point, Mich.

Prototype Installation:

Little Girl Point Park, Lake Superior, Gogebic County, Michigan. **Rings** placed directly on filter cloth on 4-inch-thick sand bedding.

Revetment slope 1 on 2.

Design wave breaking 6.5 feet high, 5.5-second period.

Construction completed in September 1974.

Rings cost $8 each, revetment cost $1.50 per square foot (Moffatt and Nichol).

Total project cost estimated at $18,860 for 300-foot-long revetment or $62.86 per foot (Brater, Armstrong and McGill, 1974).

Wave Tank Tests:

Nami rings tested at scales of 1:12.8, 1:14.7, and 1:18.6 in a 3- by 3- by 120-foot-long wave tank.

Revetment slope was 1 on 2.

These tests showed the rings were stable for a wave equivalent to a prototype breaking height of 6.5 feet and a 5-second period (Raichlew, 1973).

Design Factors:

Zero-damage wave height: 6.5 feet (model tests).

Wave runup: 0.6 to 0.7 compared to smooth slope (estimated).

Wave reflection: Moderate (estimated).

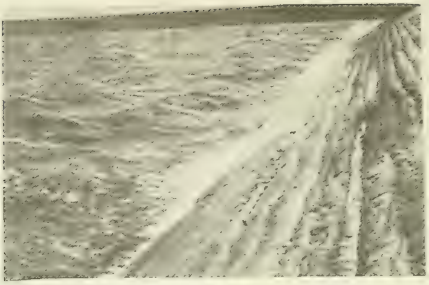
Remarks:

Rings are 1 foot high with a 2.5-foot outer diameter, a wall thickness of 3 feet, and weight of 265 pounds.

Rings opening up to trap littoral drift, reduce uplift pressure, and reduce runup.

Backfilling rings would increase stability.

SECTION



Soil cement revetment, Bonny Dam, Colo.

Prototype Installation:

Bonny Dam, Colorado.
A soil cement test section performed satisfactorily for the 10 years of this study (Holtz and Walker, 1962).

Ute Dam, New Mexico; Merritt Dam, Nebraska; Casataic Dam, California. Details of soil cement slope protection and design consideration (Portland Cement Association, 1971).

Wave Tank Tests:

Small-scale runup tests show sharp edges and small steps reduce runup.

Other design considerations (Nussbaum and Calley, 1971).

Design Factors:

Zero-damage wave height: 5 to 7 feet (estimated).

Wave runup: 0.7 to 0.8 compared to smooth slopes (estimated).

Wave reflection: Moderate (estimated).

Remarks:

Soil cement slope protection has been used on more than 30 dams (Nussbaum and Calley, 1971).

About 7- to 15-percent cement is used for mix.

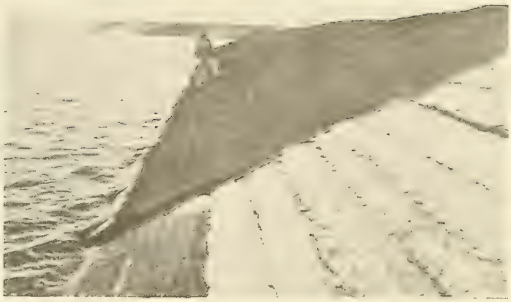
Cement and soil can be mixed at site or at a central plant.

Beach sands deficient in fines require more cement than other soil but beach sand makes good soil cement (Taylor, 1973).

For coastal use, soil cement would extend up from waterline.

If toe scour occurs, toe protection such as a cutoff wall or beach nourishment would be needed.

SECTION



Asphalt-concrete test section, Bonny Dam, Colo.

Prototype Installation:

Glen Anne Dam, California.

Upstream slope protection on dam asphalt-concrete revetment, 1 foot thick, 1 on 4 slope (The Asphalt Institute, 1965).

Point Lookout, Maryland.

Asphalt-concrete revetment protects both sides of a 2,200-foot-long causeway which extends into Chesapeake Bay. The 1 on 4 slope revetment is 4 inches thick placed in two lifts with welded wire fabric reinforcing placed between lifts (The Asphalt Institute, 1965).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: Depends on asphalt thickness.

Wave runup: 1 compared to smooth slope (estimated).

Wave reflection: High (estimated).

Remarks:

Asphalt placement underwater is difficult and expensive.

Any revetment design should consider a gravel filter with gravel or rock weep holes for pressure relief.

SECTION

Rock-asphalt mat revetment, Michiana, Mich. (Lake Michigan).

Prototype Installation:

Michiana, Lake Michigan, Michigan.
Upper beach rock-asphalt mat revetment (Brater, Armstrong and McGill, 1974).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: 2 to 4 feet (estimated).

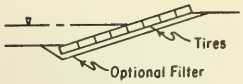
Wave runup: 0.8 to 1 compared to smooth slope (estimated).

Wave reflection: High (estimated).

Remarks:

One layer of small rock (less than 1-foot diameter) covered with asphalt to form a mat.

Any revetment design should consider a gravel filter with gravel or rock weep holes for pressure relief.



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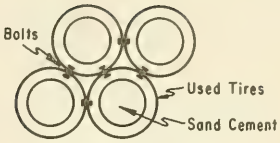


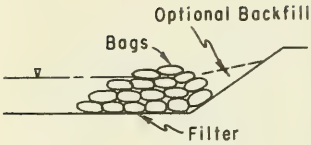
CONNECTION DETAIL

Prototype Installation:
Unknown locations.

Wave Tank Tests:
Unknown.

Design Factors:
Zero-damage wave height: 3 to 5 feet (estimated).
Wave runup: 0.6 to 0.7 compared to smooth slope (estimated).
Wave reflection: Moderate (estimated).

Remarks:
Used car tires are bolted together through the tread to form a mat.
After mat is on beach, sand cement is placed in tires for ballast.
A tire mat would be durable, flexible, and inexpensive (McCartney, 1975).



SECTION

Stacked sandbags, Cape Hatteras, N.C.

Photograph illustrates the concept of sand-cement bags. Bags in photo are sand filled, not sand-cement.

Prototype Installation:

Camp Perry, Ohio.

A 100-foot section of pyramid-piled sand-cement bags served satisfactorily as temporary protection (Kugel, 1955).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: Depends on bag size and structure thickness.

Wave runup: 0.6 to 0.8 compared to smooth slopes (estimated).

Wave reflection: Moderate (estimated).

Remarks:

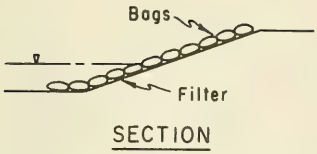
Bags would be stacked like a detached breakwater with or without backfill.

Sufficient space should be provided between the structures so bluff sloughs will not breach the structure from behind.

An apron or other toe-scour protection should be a part of the design.

Both toe-scour and differential settlement could cause failure of structure.

Ratio of sand to cement about 10 to 1 (same as soil cement).



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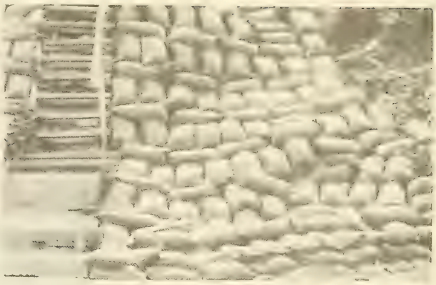


Blanket sand-cement bags, Conneaut, Ohio (Lake Erie).

Prototype Installation:
Unknown locations.

Wave Tank Tests:
Unknown.

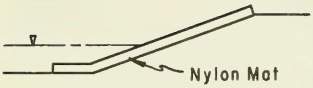
Design Factors:
Zero-damage wave height: Depends on bag weight.

Wave runup: 0.6 to 0.8 compared to smooth slope.

Wave reflection: Moderate.

Remarks:
Blanket could be one layer (similar to rock overlay) or two layers.

Blanket would be inexpensive, adjustable to settlement and scour, easily maintained, and would not seriously impair beach for recreational uses.



SECTION

Revetment mattress, Allegheny Reservoir, N.Y.

Prototype Installation:

Allegheny Reservoir, New York.
Concrete-filled nylon mat (Fabriform) was placed on a 1 on 2 slope. Slope length was 53 feet (Wilder and Koller, 1971).

Magdalene River, Columbia.
Nylon tubes 5.3 feet wide and 100 feet long were sewn together and filled with sand-asphalt mixture (Van Lookeren Compagne, 1963).

Netherlands.
Woven fabric with sewn on pockets filled with rock or rubble to provide ballast to keep fabric in position. Used as slope or toe protection (The Dock and Harbor Authority, 1974).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: Depends on mat strength.

Wave runup: 0.8 to 1 compared to smooth slope (estimated).

Wave reflection: High (estimated).

Remarks:

Concrete-filled mat will crack and break under differential settlement.

Mats could be damaged by drifting debris.

LANDING MAT

SECTION

Prototype Installation:

Mo-Mat is 0.625-inch-thick fiberglass molded into a waffle pattern weighing 1 pound per square foot (Air Logistics Corporation, 1968).

Prefabricated metal mats and membranes used to support military vehicles on beaches were tested for stability.

Prototype tests were conducted on the Brittany coast of France (U.S. Army Engineer Waterways Experiment Station, 1962).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: Depends on mat strength.

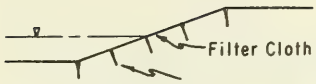
Wave runup: 0.9 to 1 compared to smooth slopes (estimated).

Wave reflection: High (estimated).

Remarks:

Steel or aluminum mats could also be used.
A weighted or buried toe would be required.
A method of anchoring the mat top would be required.

FILTER CLOTH



SECTION

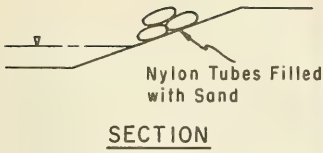
Filter cloth placement.

Prototype Installation:
Unknown locations.

Wave Tank Tests:
Unknown.

Design Factors:
Zero-damage wave height: 1 foot (estimated).
Wave runup: 0.9 to 1 compared to smooth slope (estimated).
Wave reflection: High (estimated).

Remarks:
Cloth would be easily damaged by vandalism and drifting debris.



SECTION

Sand tubes on Thyborøn Barrier Beach, North Sea coast, Denmark.

Prototype Installation:

Thyborøn Barrier, North Sea coast, Denmark.
Sand pumped into nylon tubes. Structure is three tubes, each 1-meter diameter and 100 meters long laid parallel to the beach above the waterline (Jakobsen and Nielsen, 1970).

Empire Village, Lake Michigan, Michigan.
A 42-inch-diameter Longard tube was set on filter cloth parallel to shore and filled with sand. Actual project cost was $28.30 per lineal foot of shore (Brater, Armstrong and McGill, 1974).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: Unknown.

Wave runup: 0.8 to 0.9 compared to smooth slope (estimated).

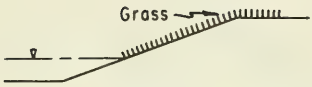
Wave reflection: High (estimated).

Remarks:

An apron or other suitable toe protection would be needed to prevent toe scour.

Tube could also be used as groin or offshore sill.

Structure could be easily damaged by vandalism or drifting debris.



SECTION

Smooth cordgrass (*Spartina Alterniflora*), Bogue Bank, N.C.

Prototype Installation:

Rappahannock River, Virginia.
Eroding banks were graded to about a 1 on 3 slope then planted with tall fescue, bermuda grass, American beachgrass and saltmeadow cordgrass.

Erosion was successfully controlled (Sharp and Vaden, 1970).

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: 0.5 foot (estimated).

Wave runup: 0.6 to 0.8 compared to smooth slope (estimated).

Wave reflection: Moderate (estimated).

Remarks:

Suggest fencing off slope to prevent cattle from eating the bank protection.

SECTION

Broken concrete-rubble revetment on waterfront, Seattle, Wash.

Prototype Installation:

Numerous rubble revetments are found in the United States as well as other countries.

Wave Tank Tests:

Unknown.

Design Factors:

Zero-damage wave height: Depends on rubble size.

Wave runup: 0.5 to 0.7 compared to smooth slope (estimated).

Wave reflection: Low (estimated).

Remarks:

Rubble can be concrete, brick, asphalt, etc.

Rubble can be cost-effective for temporary protection or where aesthetics and beach recreation use are not a concern.

McCartney, Bruce L.

Survey of coastal revetment types. — Fort Belvoir, Va. : U.S. Coastal Engineering Research Center, 1976.
49 p. : ill. (Miscellaneous report — Coastal Engineering Research Center ; no. 76-7)
Bibliography : pp. 21-23.

A review of 25 selected revetment types and a procedure for revetment design which includes identification of controlling site conditions, a comparative cost analysis method, and an example problem are presented. Design data include prototype installation examples, available model test results, and estimates of zero-damage wave heights, wave runup, and revetment wave reflection properties.

1. Revetments. I. Title. II. Series : U.S. Coastal Engineering Research Center. Miscellaneous report no. 76-7.

TC203 .U581mr no. 76-7 627 .U581mr

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